NOx Reduction for the Future with the SNCR Technology for Medium and Large Combustion Plants

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Dipl.-Ing. Bernd von der Heide
Mehldau & Steinfath
Umwelttechnik GmbH
Essen, Germany

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1. Introduction

In Western Europe the retrofitting of large coal fired boilers with NOx control systems has been concluded years ago. Since the selective catalytic reduction process (SCR) was considered as the best available technology (BAT) in the eighties and nineties, most of the boilers are equipped with SCR now.

Starting in the nineties a number of Eastern European countries joint the EU and as a consequence they also had to accept the emission limits which are in force. This means for most of the power plants that the existing boilers either have to be shut down or measures have to taken to follow the stringent regulations to control emissions like NOx.

For the SCR technology, which might be first choice, many reliable results and experiences are available to estimate the feasibility as well as investment and operating costs with high accuracy. However, beside that the investment costs for a SCR are about ten times as high as for a SNCR system other disadvantages also have to be considered.

- Installation of the catalyst often is critical especially when the boiler has a large economiser instead of an air preheater so that heat exchangers would have to be replaced to accommodate the catalyst.
- Due to the height of most boilers, accommodation of the weight of the catalyst and the steel structure would generally cause static problems.
- Pressure drop could result in higher operating costs for SCR as for SNCR and the investment volume could amount to the multiple of the cost of a SCNR system.
- The downtime of the boiler for retrofitting with SCR could cause a considerable loss of profit.

Especially during the last years, the SNCR process has been continuously improved for smaller boilers like waste incineration plants, and is widely considered now as the ‘Best Available Technology’ (BAT) for this size of boilers. With this in mind an increasing number of owners of power plants are seriously investigating today if the SNCR process is feasible for their large boilers as well. Beside the performance special attention is generally being payed to the overall cost compared to SCR.

This paper describes the tests and results with a SNCR demonstration plant in two large coal fired boilers - one in Germany and one in Poland.

2. General

In the **S**elective **N**on-**C**atalytic **R**eduction (SNCR) process of nitrogen oxides, reductants in aqueous solution (ammonia water, urea) or in gaseous form (ammonia) are injected into hot flue gases. Following the overall post-combustion reactions for

Urea $NH_2CONH_2 + 2\ NO + \frac{1}{2}\ O_2 \rightarrow 2\ N_2 + CO_2 + 2\ H_2O$

or for

Ammonia $4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$

molecular nitrogen (N_2), water vapour H_2O) and carbon dioxide (CO_2) are formed.
Basically, both urea solution and ammonia water can be used for the NOx reduction in combustion plants. Depending on the application both reductants have specific advantages and disadvantages. For an optimum NOx reduction with a minimum NH_3 slip it is "only" necessary to evenly distribute and thoroughly mix the reductant in the flue gases within the appropriate temperature window in which a NOx reduction is possible. The optimum temperature range to achieve a high NOx reduction together with a minimum consumption of reductant and a low ammonia slip is rather narrow and mainly depends on the flue gas composition.

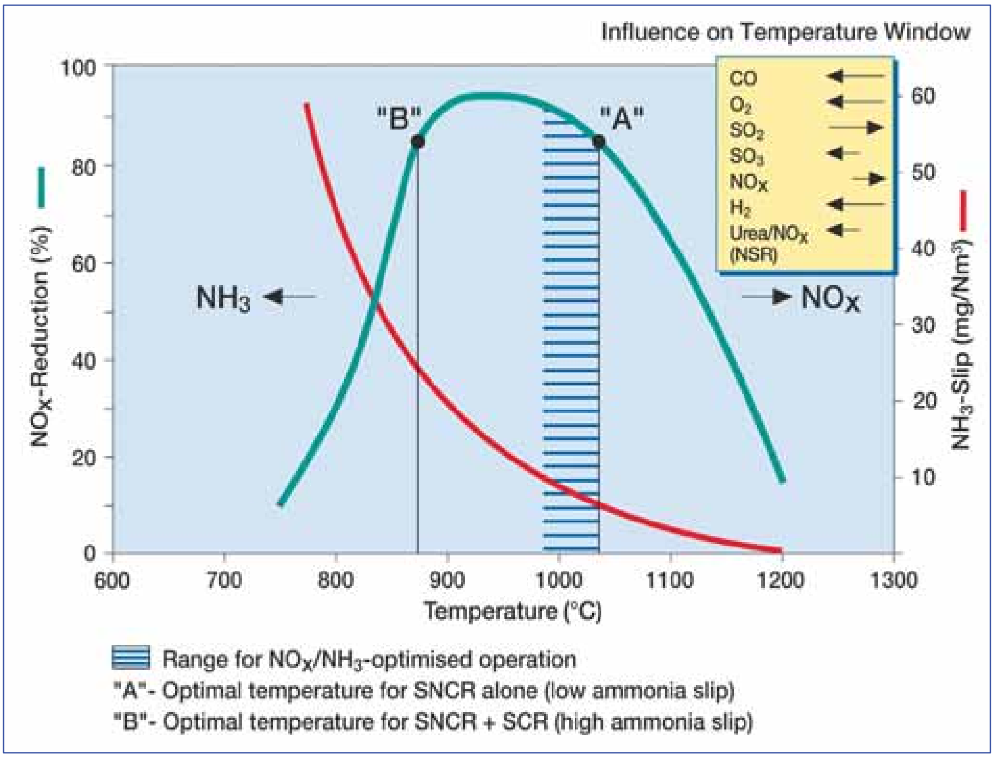


Fig. 1: NOx Reduction as a Function of Temperature

For coal-fired boilers the optimum temperature lies between about 960 and 1020 °C Above this temperature range ammonia is oxidised to an increasing extent, i. e. nitrogen oxides are formed **(Figure 1).**

At lower temperatures the reaction rate is slowed down, causing an ammonia slip which may result in the formation of ammonia salts and may lead to secondary problems, downstream the flue gas path. Therefore, the ammonia slip should be kept at a minimum.

Since the temperatures over the cross-section in the furnace are rarely uniform and often considerable imbalances are found, special measures need to be taken to identify the right positions for the injectors and distribute the reductant properly into the flue gas under all operating conditions.
These chemical reactions are similar if catalysts are used and also take place in a limited temperature window, which however is in a range outside the furnace or the boiler.

The objective of all NOx control technologies is to reach a high NOx reduction with a minimum consumption of reagent while the ammonia slip must be kept low at the same time. This only can be achieved with an even distribution of the reagents in the flue gas at the right temperature.

The urea based SNCR process of M&S consists of the following four steps

1. Distribution and mixing of the liquid droplets in the flue gas stream
2. Evaporation of the water in which the reagent chemicals are diluted
3. Decomposition of the reagent into reactive species
4. Gas-phase reaction between NH_2 and NOx

Besides the distribution and mixing in the flue gas, the size of the droplets is very important for the results of the process. Droplets, which are too small, would evaporate too fast and possibly lead to a reaction at a too high temperature so that more NOx would be formed.

Droplets which are to large, would evaporate too slowly so that the reaction would take place at the lower side or outside the temperature window, which would lead to an increasing of the ammonia slip, and decreasing of the NOx reduction.

The major difference between both reductants, i.e. ammonia water and urea, is shown in a strongly simplified diagram in **Figure 2**. Urea dissolved in water only can be decomposed into reactive NH2-species after the water enclosing the urea particles has been completely evaporated. The place in the flue gas where the reaction is to take place can be defined in advance by means of the water droplet size and the resulting penetration depth. If the water droplet is big enough, injection is possible into a place that is too hot for a NOx reduction, because the reaction can take place downstream the injection point in a colder place within the flue gas. The mass of the dilution water, which is additionally used as a carrier medium for urea solution, ensures a high penetration depth at rather low energy consumption, and may cool down the flue gas to the desired temperature, if necessary.

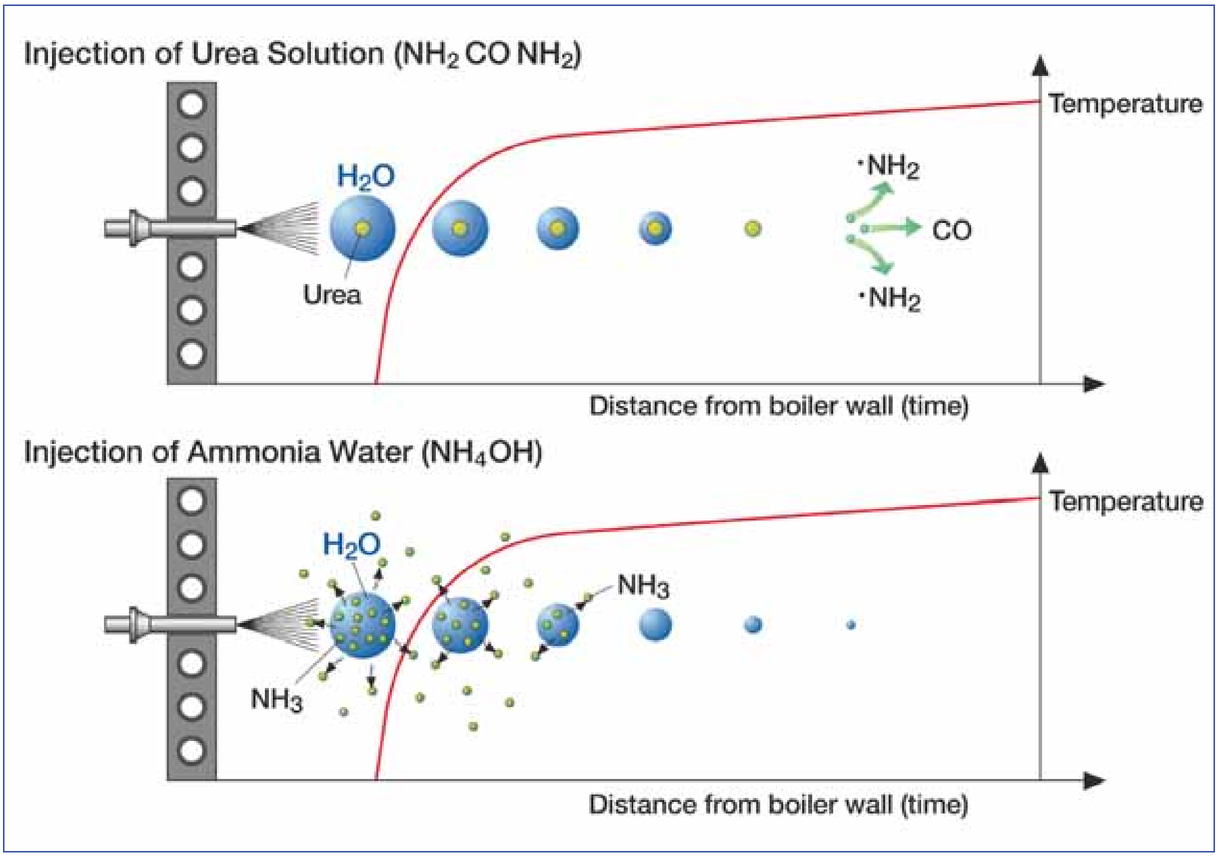


Fig. 2: NOx Reduction with Urea versus Ammonia Water

In contrast, in plants using ammonia water the ammonia evaporates immediately when the ammonia water is being heated up respectively having entered the furnace. To ensure an optimum penetration depth more energy is required because of the lower mass of ammonia in gaseous form compared to a water droplet. In older plants this is accomplished by increasing the steam or air volume used as a driving medium.

However, a homogeneous distribution is very difficult to obtain as flue gases are very viscous and in general it is difficult to mix different gases. This disadvantage, which has often caused a higher ammonia slip in plants with ammonia water, can be compensated for to a major extent if dilution water is used as a carrier medium also for ammonia.

With the higher mass flow of the water a higher negative pressure is achieved in the jet stream after the nozzle compared to compressed air or steam alone **(Figure 3)**. Due to the negative pressure the flue gas is sucked into the jet stream together with the ammonia and mixed. With this concept comparatively good results are obtained today with regard to NOx reduction and ammonia slip, which have been the standard for urea solution already since the nineties.

Ammonia is a toxic and easily inflammable gas, readily soluble in water at ambient temperature. Operators consider ammonia water with a concentration just under 25% to be the optimum fluid for approval reasons. However, if the temperature increases, ammonia rapidly evaporates from water.

At 38 °C the partial pressure of ammonia reaches as much as 1 bar, and therefore stringent safety requirement have to be followed when storing it. Such safety requirements include, for instance, ex-proof equipment in the tank, ammonia sensors, illuminated wind direction indicators, flame arrestors at relief and under pressure valves, gas exchange pipes, emergency showers, eye showers, etc.

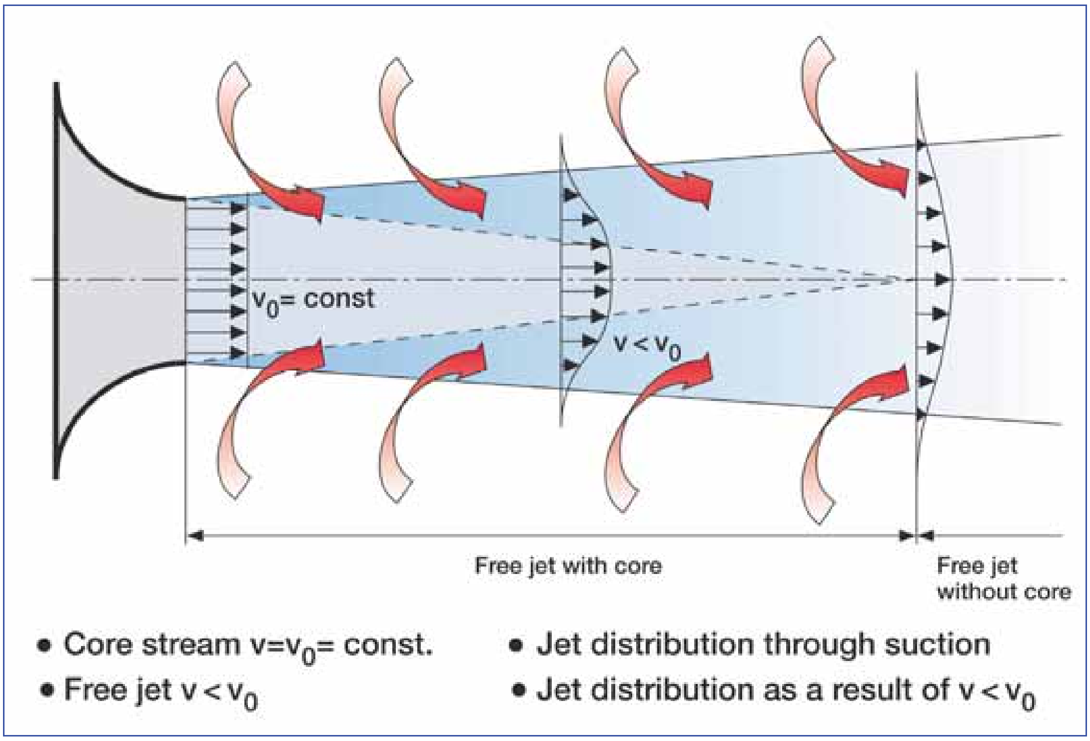


Fig. 3: Mixing Flue Gas with Free Jet

Due to the chemical bonding of ammonia in the urea molecule, urea solutions may be heated up to 106 °C without ammonia gas evaporating. In contrast, the decomposition of urea into ammonia and carbon dioxide gas does not start below 130 °C and reaches its maximum at about 380 °C. Such high temperatures are not reached when the chemicals are stored, and therefore safety precautions as required for ammonia water are not necessary.

The urea solution storage tanks are filled by means of compressed air generally generated by on-board compressors of the delivery vehicles. This method is not permitted for ammonia water, as the displaced gas volume from the storage tanks needs to be conveyed into the tank of the delivery vehicle via the gas exchange pipeline. Moreover, the less costly submersible pumps are not permitted for conveying the ammonia water from the tank to the injection lances as they involve an explosion risk. Under the German Federal Water Act (WHG) urea solution is allocated to the German water hazard class 1. This means it is only required to prevent urea from getting into the ground water.

Ammonia water, however, belongs to the water hazard class 2, and is subject to the German regulations TRD 451 + 452 for steam boilers or equivalent due to their high environmental hazard potential.

3. Concept for Plants designed for NOx < 200 mg/Nm³

The simplified process flow scheme **(Figure 4)** shows the function and the scope of equipment of a typical SNCR system for urea solution as installed in numerous combustion plants with various fuels which are operated according to the current regulations with NOx reduction rates of up to 50 - 60%. Subject to the specific requirements these plants are generally equipped with one or two injection levels, which can be operated alternatively depending on the boiler load and/or the flue gas temperature.

With this concept NOx values of 120 to 150 mg/Nm³ and a NH_3 slip of 10 to 15 mg/Nm^3 can be maintained if the injection lances are arranged in such a way that a wide temperature window for the injection can be covered. Temperature variations and imbalances, which cause insufficient reduction in one area, are compensated for by higher reduction rates in another area. To follow larger variations and imbalances in temperatures during operation, two injection levels - which can be operated alternatively depending on the mean temperature measured at the end of the furnace - have proven to be successful.
Under favourable operating conditions as can be found when homogeneous fuels are burnt at constant loads, even NOx clean gas values below 100 mg/Nm^3 can be obtained with this configuration while the NH_3 slip still remains moderate.

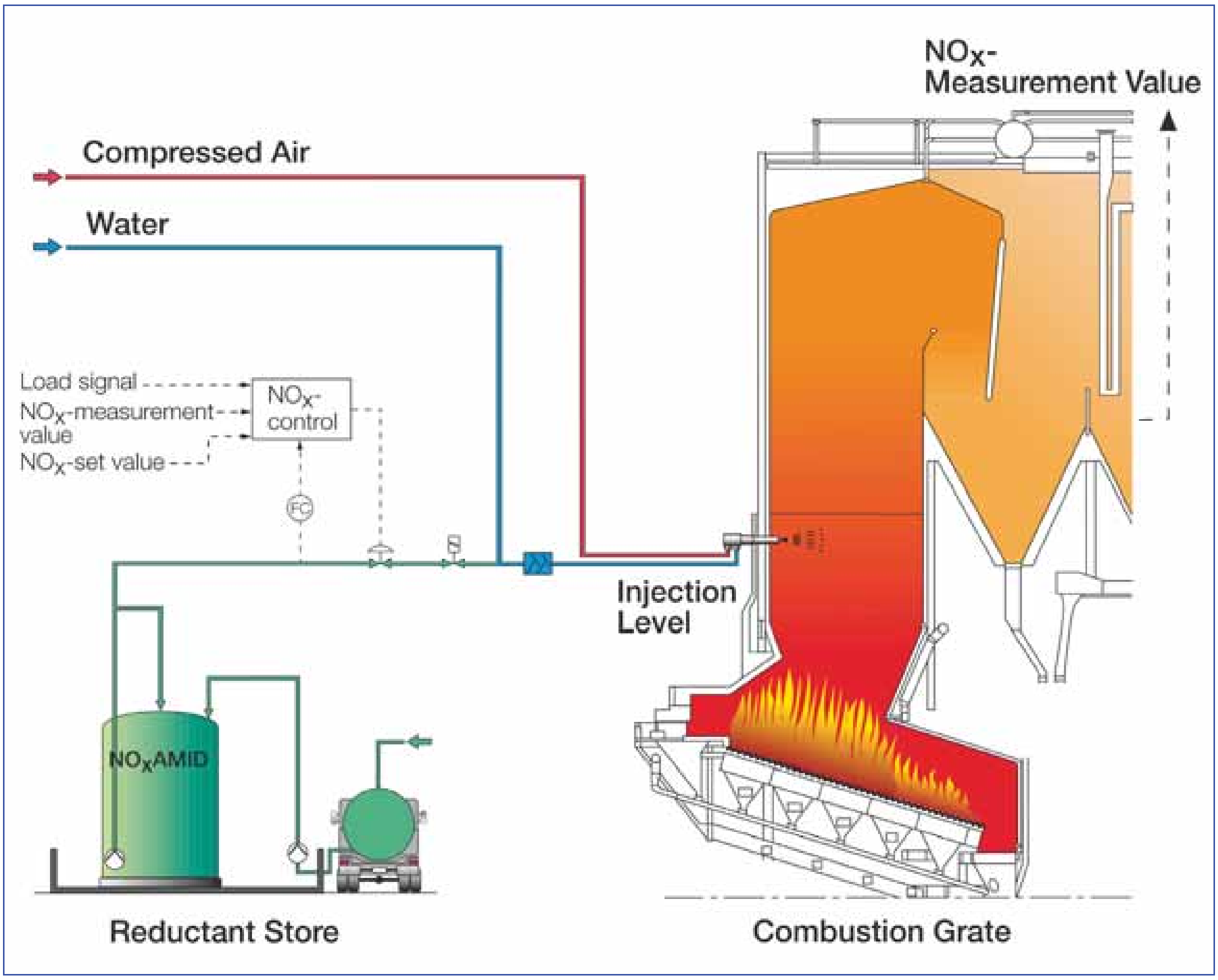


Fig. 4: Process Flow Scheme with Urea Solution

4. Temperature Measurements and Demonstration Plant (Test Plant)

In order to get a feeling whether the SNCR process could be suited for existing boilers, as a first step, realistic temperatures at possible positions for the injection of the reductant need to be obtained. Since the temperatures measured with thermocouples which are usually installed at the boiler walls are affected by radiation influences of flames and boiler walls a suction pyrometer generally will be used. It consists of a water-cooled lance with a thermocouple (Ni-CrNi) on its tip. The thermocouple is protected against radiation with a ceramic shield. The hot flue gases are being sucked into the lance in such a way that the real gas temperature can be measured. The negative pressure required is generated by an ejector with compressed air.

However, to obtain more reliable information whether the required NOx reduction could be achieved with the SNCR process it is recommendable to perform so-called "tentative tests“ with a temporary test installation. These tests give valuable information which efforts are required with regard to the design and the equipment of the commercial SNCR plant and which performance can be expected and guaranteed under changing operating conditions.

In order to keep the technical efforts and the costs of tests as low as possible, technical shortages of the existing demonstration plant, which had been designed for testing at smaller boilers, were deliberately accepted. The plant consists of a pumping module and metering and mixing module with eight exits, flow meters and all necessary armatures **(Figure 5)**.
The modifications of the boilers are usually limited to the minimum necessary. For instance, time- and cost consuming bending of tubes in the boiler walls for accommodating the injection lances are generally avoided. For the injectors sometimes only holes of a diameter of approx 10 mm in the fins between the boiler tubes can be provided **(Figure 6)**. Injection lances often also cannot be installed in boiler areas with difficult access, so that it is clear from the beginning on that an optimum penetration and distribution of the reagent over the whole cross section in the furnace could not be expected.

Fig. 5: Demonstration Plant (Metering and Mixing Module, Pumping Module, Storage Container for NOxAMID40)

Regardless whether urea or ammonia water will be used for the commercial plant the tests mostly are being performed with urea solution as reductant. The reason is that urea solution is much easier to handle than ammonia water and, therefore, it makes not much sense to use ammonia water during the short duration of the tests. From the performance point of view both reductants are comparable, so that the test results provide reliable information for a commercial plant regardless whether urea solution or ammonia water will be used as reductant. Tests have been conducted in several boilers with a capacity up to 225 MWel in Germany, Czech Republic and Poland.

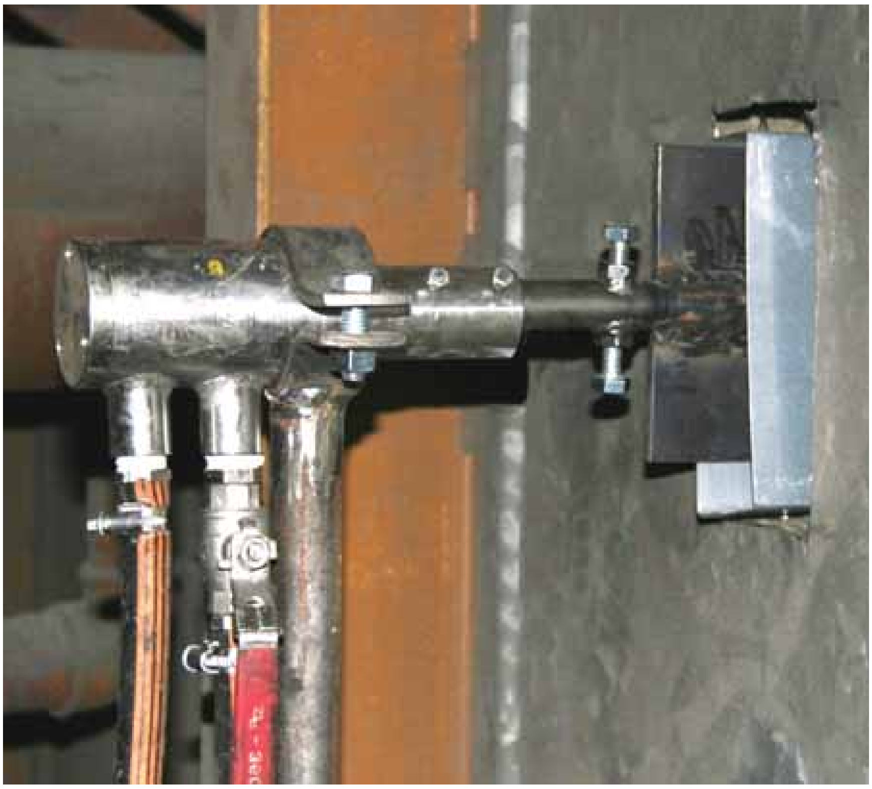


Fig. 6: Temporary Installation of Injector

Below in **table 1**, a number of limitations are listed which were affecting the tests at several locations. Compared to the demonstration plant a commercial plant designed for the relevant application will provide better results.

Limitations during Trials

1. Openings for the Injectors had to be drilled into the Fins of the Membrane Walls between the Boiler Tubes in order to avoid cutting, bending and welding of the Tubes. Therefore, Openings for Injectors are too small for larger Nozzles to assure sufficient penetration into the Furnace.
2. Openings in Front Wall could not be used for Injection.
   Distribution of the Reductant was not optimal.
3. Only a few Openings were large enough for using the Suction Pyrometers. Most of Temperature Measurements only had to be taken with Thermocouples.
4. Openings for Temperature Measurements were not sufficient to receive enough Information on the Temperature Profile to define the best Locations for the Injectors.
5. Changing of Injectors during Testing was very Time Consuming
6. Imbalances of the Flue Gas Temperatures in the Furnace could not be determined

Table 1

5. Combustion Chamber Diagnosis with the agam System

The temperature measurements with suction pyrometers performed in a 200 MW coal fired boiler and the readings from the permanently installed thermocouples only permit rough assumptions regarding the temperatures occurring in the individual potential injection levels under the respective boiler loads. Beyond these assumptions the temperature distribution and imbalances resulting from the boiler load, the ignition behaviour, the burner configuration, etc. may vary strongly.

Moreover, the temperature window moves further upwards in the combustion chamber due to the increasing degree of contamination of the heating surfaces in the course of the operating time. Depending on the fuel type, fuel distribution and air supply, temperature imbalances of up to 150 °C - and sometimes even higher - are typical. The flue gas temperatures measured with thermocouples and averaged can be used as reference temperatures to a limited extent only as these average temperatures do not say anything about the temperature profile or the imbalances within the injection levels. Moreover, also radiations from the furnace walls are affecting the measurements, resulting in deviations from real flue gas temperatures of 60 to 100 K. In addition, deposits on thermocouples lead to an increasing insulation effect in the course of the operating time, and hence temperature measurements of the process control system are time-delayed in a range of 10 minutes and longer depending on the thickness of such deposits.

To ensure that the reductant is injected always in the upper range of the temperature window under all possible operation conditions, i.e. in the range where the NOx reduction is highest and the NH_3 slip is lowest, acoustic gas temperature measurement systems (agam) are provided in plants where high performance is required. Agam is measuring the real gas temperatures near the injection points and determining the temperature profiles across the entire combustion chamber cross-section.

The system consists of transmitter and receiver units of an identical mechanical and electrical design mounted to the walls of the combustion chamber and an external control unit **(Figure 7 and 8)**. During the measurement the solenoid valve in the compressed air line on the transmitter side is opened, generating acoustic signals. The signals are recorded simultaneously on the transmitter side and on the receiver side. The digitalised signals are used to measure the transmission time. As the distance is known, the sound velocity can be determined, which is then converted into a temperature, i.e. the so-called path temperature. With several combined transmitter/receiver units acting on one level multiple path configurations are obtained to determine the two-dimensional temperature distribution in one level immediately and without delay.

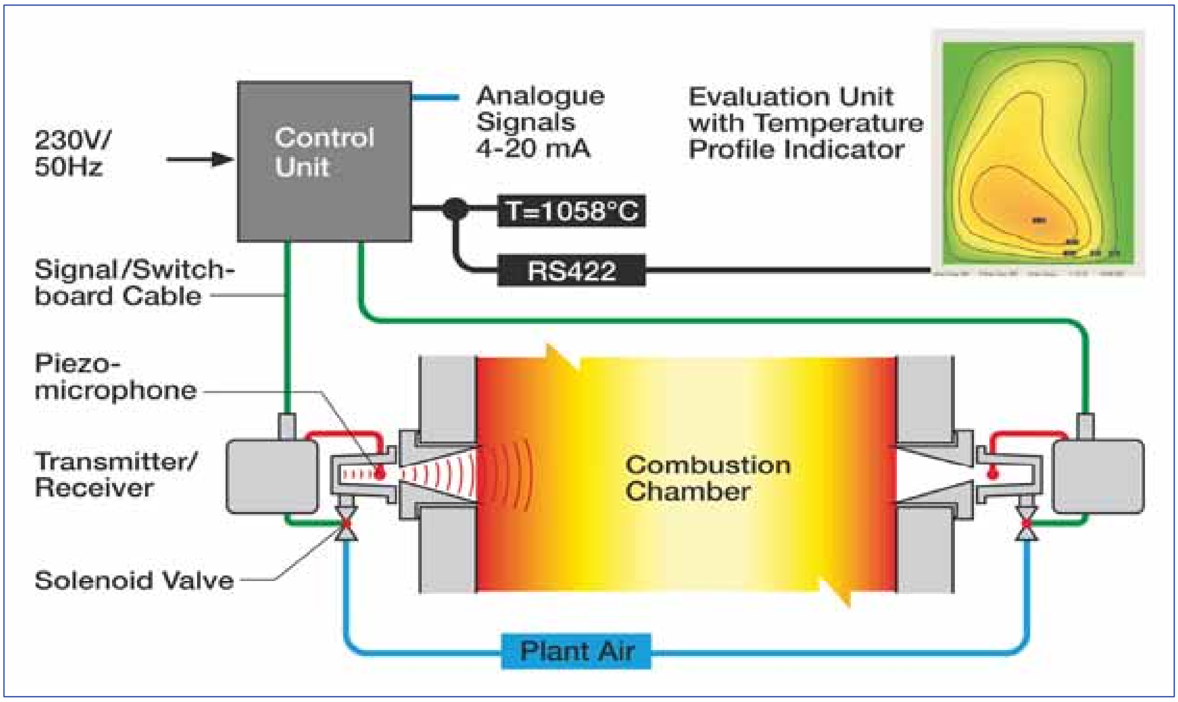
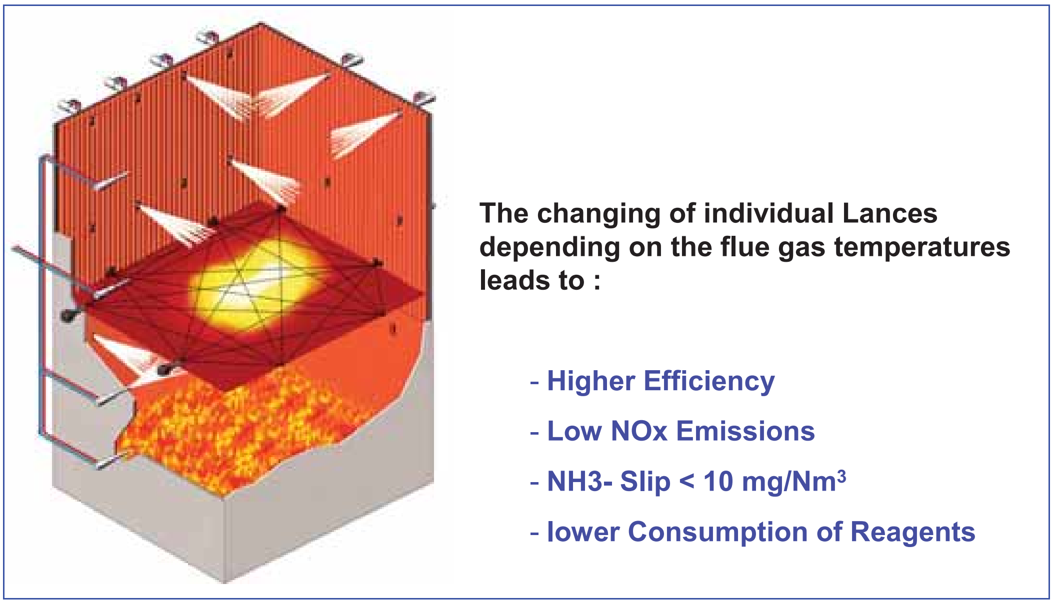


Fig. 7: Basic Configuration of Acoustic Gas Temperatures Measurement System (agam)

Fig. 8: SNCR Injection Lances with agam

The temperature profile determined is divided into sections and can be assigned to individual lances or groups of lances to switch them to another level depending on the flue gas temperature measured. This ensures that the reductant gets to the locations, which are most effective for the reaction even at rapidly varying flue gas temperatures, and the SNCR plant is always operated in the optimum temperature range with regard to the degree of NOx reduction, NH_3 slip and reductant consumption **(Figure 9)**.



The changing of individual Lances depending on the flue gas temperatures leads to :

- Higher Efficiency
- Low NOx Emissions
- NH3- Slip < 10 mg/Nm^3
- lower Consumption of Reagents

Fig. 9: Changing of Individual Lances depending on Flue Gas Temperature

After the basic decision had been made in favour of the SNCR process, a temporary acoustic gas measurement system (agam) was installed some time before the final decision was made, the order for the commercial SNCR was placed. The intention was to obtain as many detailed information as possible and ensure maximum certainty for the engineering of the commercial SNCR plant - in particular regarding the configuration and confirmation of the SNCR injection levels and positions.

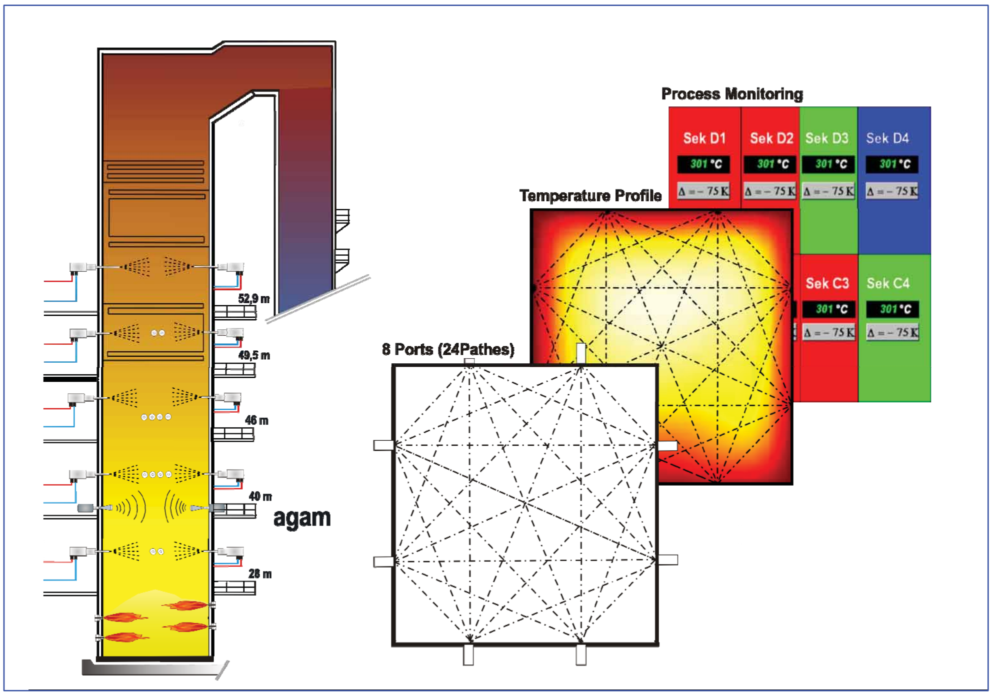


Fig. 10: Boiler with 5 Injection Levels and agam

The temperature measurements were performed at the end of the combustion chamber (39 m) with different loads and configurations of pulverisers. The positions of the agam measurement level and the burner levels are shown in **Figure 10**, it also shows the arrangement of the 8 transmitter and receiver units as well as the paths of the acoustic measurement. On the basis of the 24 measured path values the temperature distribution (isotherms) is calculated tomographically.

Four symmetric zone temperatures are determined from the temperature matrix. The surface average value is used to calculate deviations for the zones. The monitor of the acoustic diagnostic computer displays the isotherms, the configuration of the 16 zones with indication of the deviations from the average value as well as the zone or surface average value **(Figure 11)**. The colour in the zones change from green to red or blue if the deviation from the average value exceeds +25 K or is lower than –25 K. Under the zone or isotherm diagram the four zone deviations from the average value are shown as trends.

Zonenwerte NEU

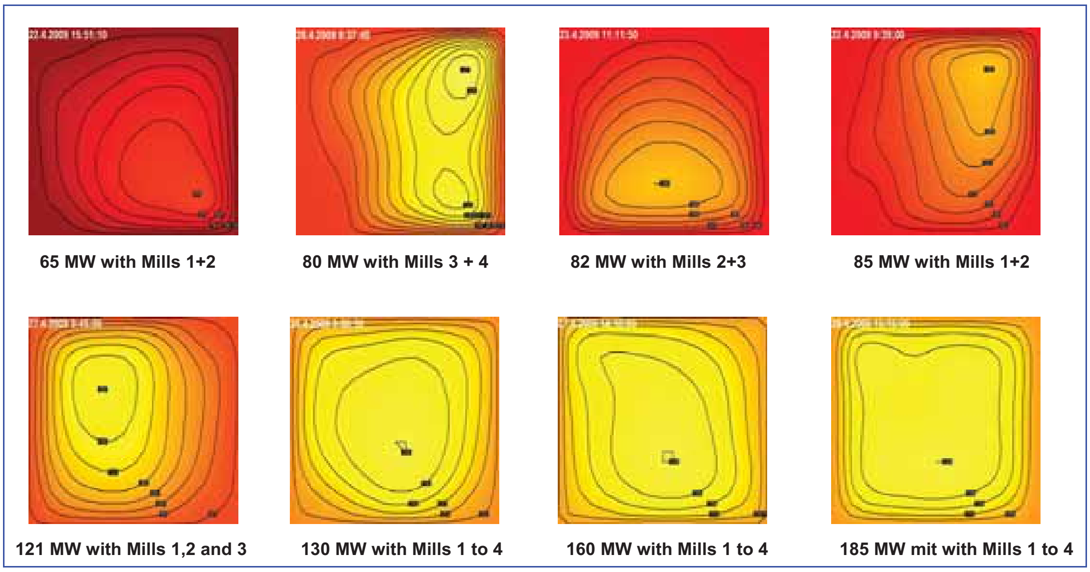
Zonenmittelwert 913 °C

Zone 01 935 °C	Zone 02 1023 °C	Zone 03 991 °C	Zone 04 880 °C
Zone 05 855 °C	Zone 06 885 °C	Zone 07 872 °C	Zone 08 833 °C
Zone 09 942 °C	Zone 10 1015 °C	Zone 11 937 °C	Zone 12 810 °C
Zone 13 904 °C	Zone 14 865 °C	Zone 15 909 °C	Zone 16 802 °C

Fig. 11: agam - Configuration of 16 Temperature Zones

The average temperature at the end of the combustion chamber varies between about 750 °C under low load (45 MW, burner level 1) and 1155 °C under full load (185 MW, with all burners in operation) **(Figure 12)**.

The following engineering concept was determined on the basis of the analyses of temperature measurements and the tests with the SNCR demonstration plant for a 200 MWel coal fired plant.



65 MW with Mills 1+2

80 MW with Mills 3 + 4

82 MW with Mills 2+3

85 MW with Mills 1+2

121 MW with Mills 1,2 and 3

130 MW with Mills 1 to 4

160 MW with Mills 1 to 4

185 MW mit with Mills 1 to 4

Fig. 12: Temperature Profiles in agam Measurement Level at different Boiler Loads Configurations of Mills

6. Technical Concept of the SNCR Plant for a 200 MWel Coal Fired Boiler

The simplified process flow chart **(Figure 13)** shows the function and the scope of supply of the commercial SNCR plant as planned and implemented in the power plant. Due to the major temperature differences between low load (20%) and full load as well as the extreme temperature imbalances, five injection levels are arranged between 26 and 51,8 m. The injectors are arranged in such a way that the right and the left sides of the boiler can be controlled independently from each other. Each injection lance may be individually activated or deactivated. The SNCR plant in its final stage mainly consists of the key components described below. Compared to a plant operated with urea solution, more sophisticated design and implementation requirements are to be considered for the operation with ammonia water since safety requirements are more stringent.

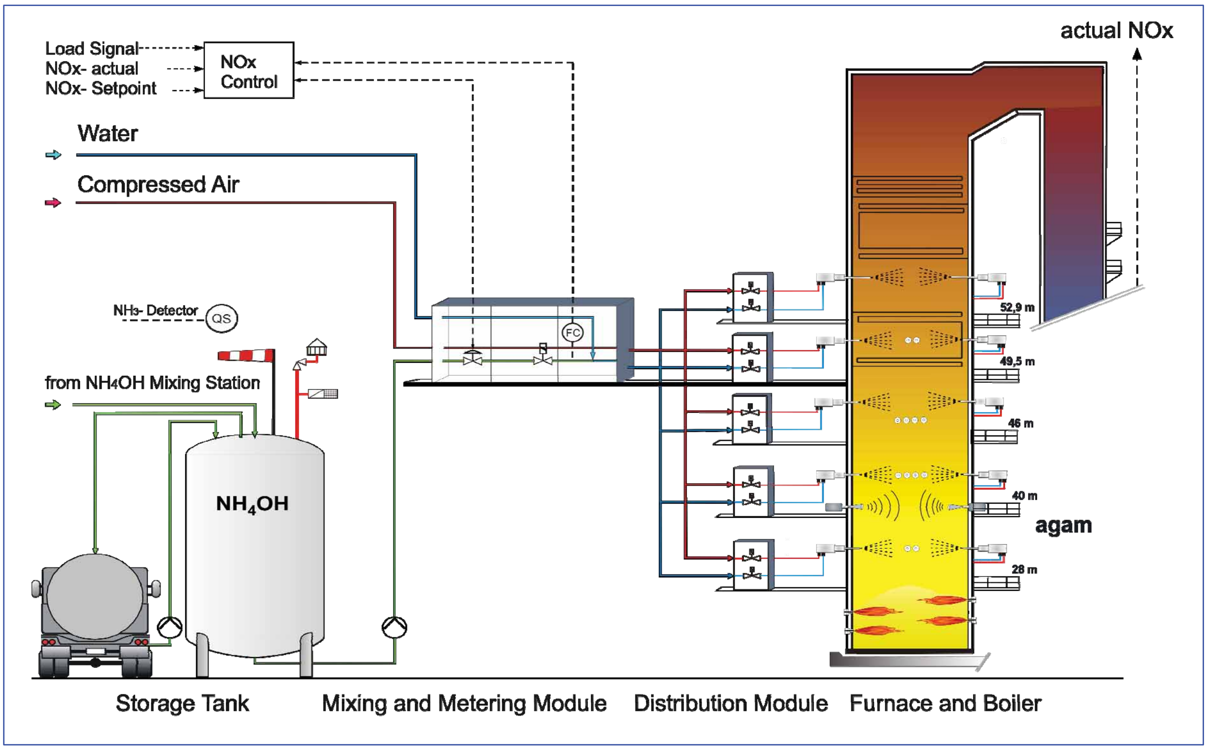


Fig. 13: Flow Diagram of SNCR with five Injection Levels and agam

6.1 Reductant Storage and Supply

Ammonia water which is used as a reductant is mixed at the power plant site from pressure-liquefied ammonia used for the SCR plants installed for the other boilers, and is pumped through a pipeline to the storage tank of stainless steel. Alternatively, filling from tank trucks is possible. Ammonia vapours leaking from the storage tank are absorbed in a tank filled with water and returned into the storage tank; when a certain concentration of ammonia is reached. Therefore, a gas exchange pipe is not required **(Figure 14 and 15)**.

In addition, the comprehensive safety equipment includes ammonia sensors, flame arresters, full-body and eye showers, wind direction indicators etc.

Ammonia water is classified as a substance of the water hazard class 2 (dangerous to water) and, in addition, falls under the European standard EN 12952-14:2004 (formerly TRD 451 and 452) due to its high hazard potential for the environment.

When handling ammonia water a difference must be made between ammonia water in the tank and pipes and gaseous ammonia after vaporisation above the liquid in the tank and in case of leakage. Therefore, the special hazard potentials of both dissolved and gaseous ammonia need to be considered.

Figure 14: Storage Tank for Ammonia Water with Pumping Station

Figure 15: Storage Tank for Urea Solution

6.2 Transfer pumps

From the storage tank the reductants are directly pumped back into the tank via a recirculation line and a pressure retaining valve. A line branches from this ring line and leads to the two mixing and measuring modules. Control valves supply the reductant amount required for denitrification, whereas the excess ammonia water is returned to the tank. The less costly submersible pumps are not permitted for conveying the ammonia water from the tank to the injection lances as they involve an explosion risk. For the SNCR plant leak-free magnetic coupled pumps are used.

Insulation and heating of the tank and pipes are not required since the ammonia content lowers the freezing point of water and crystallisation of ammonia is not possible. The freezing point of ammonia water 25%, for instance, is - 57°C.

6.3 Mixing and measuring modules

The mixing and measuring modules mainly serve to:

- measure all flow rates (reductant, water, air);
- mix the reductant with process water;
- interrupt the reductant supply in case of operating trouble.

Because of the number of injection levels and injectors, two distribution modules were installed on each of the five injection levels to distribute the liquids and the atomising air to the injection lances. All modules contain the necessary armatures as well as measuring and control instruments for the flow rates and the pressures of the reductants, the compressed air and the process water **(Figure 16)**.

Fig. 16: Metering and Mixing Module **Distribution Module**

The pressure of the liquids and the compressed air depends on the required penetration into the boiler and the droplet size, and usually ranges from 3.5 to 4 bar at the inlet of the injection lances, resulting in a pressure of about 4 to 4.5 bar at pressure reducing valve at the inlet of the mixing and metering module considering the pressure loss inside the module and the pipes to the lances.

All components of the modules are mounted on a base frame. To protect the instruments, in particular, against dust and splashing water, the module is housed in a cabinet. Glass doors are provided to make it easier to take readings and even facilitate readings just in passing by. In particular, in plants operated with ammonia water, glass doors help minimise the hazard potential for the maintenance staff since any leaks can be identified without opening the doors and exposing the staff to toxic vapours.

Regulations regarding mixing and measuring modules operated with ammonia water are more stringent than those applying to urea solution. As a minimum requirement pipes and fittings must be provided with the pressure rating PN10. A higher pressure rating as sometimes required by several operators is not recommended since this would also require higher measuring ranges and scalings of the measuring instruments, such as manometers, and thus affect the accuracy of readings. For all fittings and materials 3.1. certificates are required. To prevent hazards from leakage, ammonia detectors are provided triggering an alarm at 400 ppm ammonia and switching off the pumps at 800 ppm.

6.4 Injection system

To ensure optimum NOx reduction nozzles are used, which are designed to generate the size and the velocity of the droplets for the boiler geometry and the flue gas conditions. Each injection lance is provided with one or more nozzles to ensure an even distribution of the water-solved reductant in the flue gas. For the ease of handling compressed air instead of steam is used as a driving agent in the German power plant. However, both agents are suited from the process point of view. For the urea-containing reductants NOxAMID normal process water can be used as dilution water serving as the carrier medium. Since NOxAMID contains special additives preventing the precipitation of lime, soft water is not necessary. However, demineralised water or deionised water is mandatory for ammonia water since, otherwise, lime deposits may cause fittings and nozzles getting clogged just within one day sometimes.

The ammonia water / demineralised water mixture is injected by means of wall lances, in order to avoid the wear of lances by corrosion due to the hot and aggressive flue gases.

6.5 Process control

For technical reasons it is not possible in the SNCR process to measure NOx of the raw and clean gas values simultaneously. Since measurements are performed in the colder flue gas downstream of the boiler, the NOx content can alternatively be measured only with or without reductant injection. Due to the time delay between injection into combustion via the NOx measurement in the stack, sampling, the analysis and the distance of the newly set concentration of the reductant from the control valve to the lances, the reductant volume depending on the boiler load needs to be roughly calculated in advance to respond to the changing operating conditions as quickly as possible.

This is effected by means of a load signal, the defined NOx clean gas value and the resulting NOx charge. Depending on the measured actual NOx clean gas value, the volume is continuously corrected. To avoid extreme variations of the reductant volumes, a constant base volume is preselected depending on the expected mode of operation, serving as the minimum limit value for the reductant volume.

The SNCR plants are switched on and, as appropriate, the injection levels - or individual lances as in the subject SNCR plant - are changed depending on the combustion chamber temperature in the sections determined with the acoustic temperature measurement system and allocated to the individual lances. The process is controlled via a stand-alone PLC, but may be also controlled via the process control system of the overall plant. Visualisation is effected by a bus connection with the control room as it is common state of the art, in particular, for larger combustion plants.

7. Ammonia slip

NH_3 may form ammonia salts if SO_3 and/or HCl are contained in the flue gas. These salts may have a considerable impact on the operation and availability of the systems downstream in the plant. This may be hold true for plants with high SO_3 and low dust concentrations, such as heavy oil firing systems. However, such contemplations often do not consider that SCR processes partially involve much bigger problems with such fuels due to high SO_3 and vanadium pentoxide contents. SO_3 reacts with the ammonia injected for reducing NOx also in the catalyst and forms ammonium salts generating deposits with the fine dust. Moreover, vanadium pentoxide increases the reactivity of the catalyst, increasing the conversion rate of SO_2 into SO_3 and causing the formation of sulphuric acid and the related corrosion problems.

Contrary to the widely spread opinion, it is rather seldom that the formation of ammonium salts in coal-fired boilers due to the NH_3 slip from SNCR plants causes technical problems, such as deposits of ammonium hydrogen sulphate in the heat exchangers and resulting pressure losses. Ammonium hydrogen sulphate mainly accumulates in the fly ash and is separated in the filter. If the plant concept is appropriate, even the loading of the fly ash and the by-products from flue gas cleaning is kept within acceptable limits. In special cases a small catalyst disc may be subsequently installed at the boiler end without great effort to limit the NH_3 slip and achieve additional NOx separation.

8. Availability of SNCR

The availability of the overall plants is practically not affected by SNCR systems. Generally values of 98 or 99% can be guaranteed. All components critical for its operation, such as pumps, which may affect the availability of the plant, are provided redundantly. The injection lances in contact with the flue gas, which need to be regularly checked and serviced as wearing parts, may be conveniently checked during operation and replaced well in time if necessary. In order not to jeopardise the NOx half-hourly mean values, individual lances should be replaced one after the other. Used lances may be reconditioned by cutting or replacing the protection pipes. Occasionally, also the nozzles need to be replaced.

The installed armatures are designed for long term operation usually, do not need to be replaced during the operation if the SNCR plant is regularly maintained during scheduled shutdowns of the overall plant. However, if unexpected damage occurs, most of the problems, such as replacement of flow meters and manometers, may be corrected during the operation. Control valves might be more critical. However, they are provided with a by-pass such that the relevant flow rates of the reductants need to be manually adjusted until the relating control valve has been replaced or repaired.

Predictive spare part storage and regular maintenance during scheduled plant shutdowns will practically avoid and/or minimise all problems during the operation. If, however, an unscheduled shutdown of the SNCR plant becomes necessary, problems may be corrected within a short period of time such that the daily mean values are not even jeopardised in such event.

Lime deposits in the piping system, including armatures and injection lances, can only be avoided if urea solutions with a suitable additive (e.g. NOxAMID) are used. If the SNCR plant is operated with ammonia water as a reductant, it is mandatory to use demineralised or deionised water as the dilution water. The removal of lime deposits is a very time-consuming procedure and may have a considerable impact on the availability of the overall plant.

The plant in the German power plant is provided with an automatic data acquisition system to facilitate fault diagnosis and settings via telephone. The higher investment cost of such a system will amortise within a short period of time since the expenses of costly visits of service engineers can be avoided.

9. SNCR demonstration in a Coal Fired Plant (225 MWel)

In a power plant five coal fired boilers with a capacity of 225 MWel each are installed. The objective of the demonstration with SNCR was to provide reliable information that NOx reductions of min. 25 % can be safely achieved at all boiler loads between 40 to 100 %. Temperature measurements which only could be conducted at two openings at 47,4 m showed that there are temperature imbalances of more than 120 K between the measuring points. Further measurements were not possible, since there were no more openings large enough for accommodating the pyrometer lance. The urea was injected during the tests through openings at levels 37,9 m and 47,4 m from the front wall and at 47,4 m also from the side walls **(Figure 17)**.

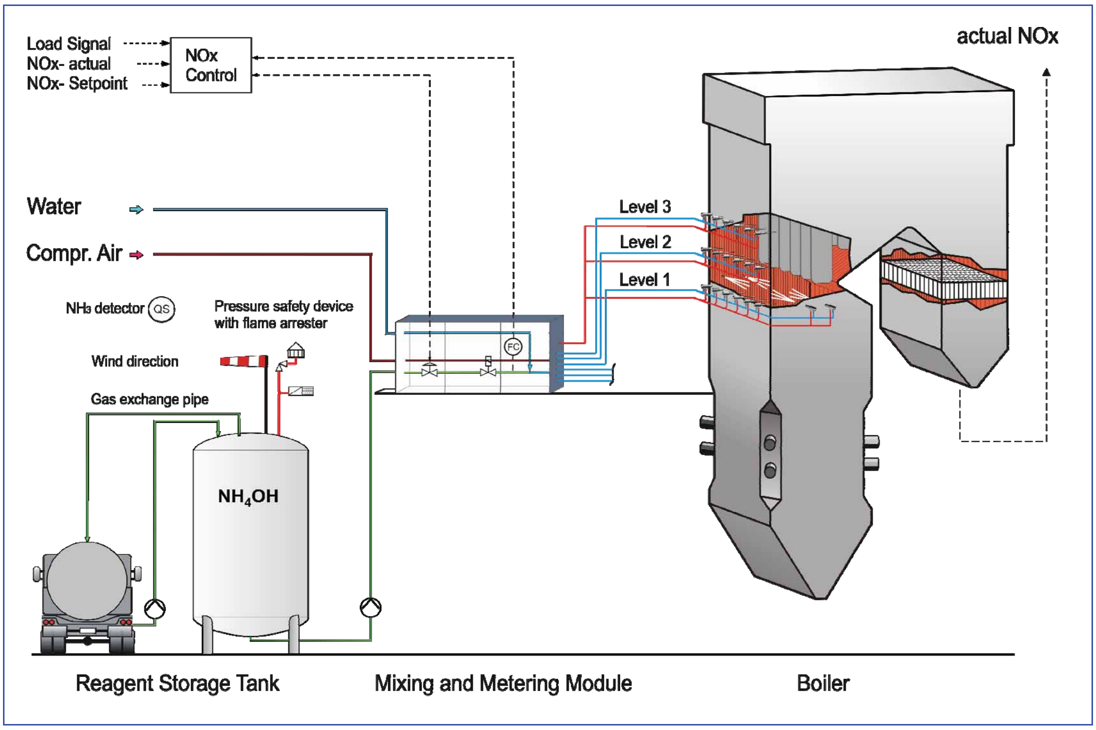


Fig. 17: Flow Diagram for Commercial SNCR with Catalyst

Despite these difficulties the results were very positive. The required NOx reduction of 25 % was exceeded at all loads considerably **(Table 2)** and reached almost 60 % at 75 % load. For a commercial plant a third level for injecting the reductant would improve the performance especially with regard to efficiency and ammonia slip. To keep the ammonia slip low a small catalyst at the end of the boiler is considered. However, with an acoustic temperature measurement system (agam), similar as installed in the German boiler, the reductant could be injected more precisely into the optimum temperatures so that the slip could be maintained low enough to keep the ammonia concentration in the fly ash below an acceptable limit, so that an additional catalyst slice would not be needed. In samples which were taken from the fly ash, an ammonia content was analysed between 40 and 80 mg/kg fly ash.

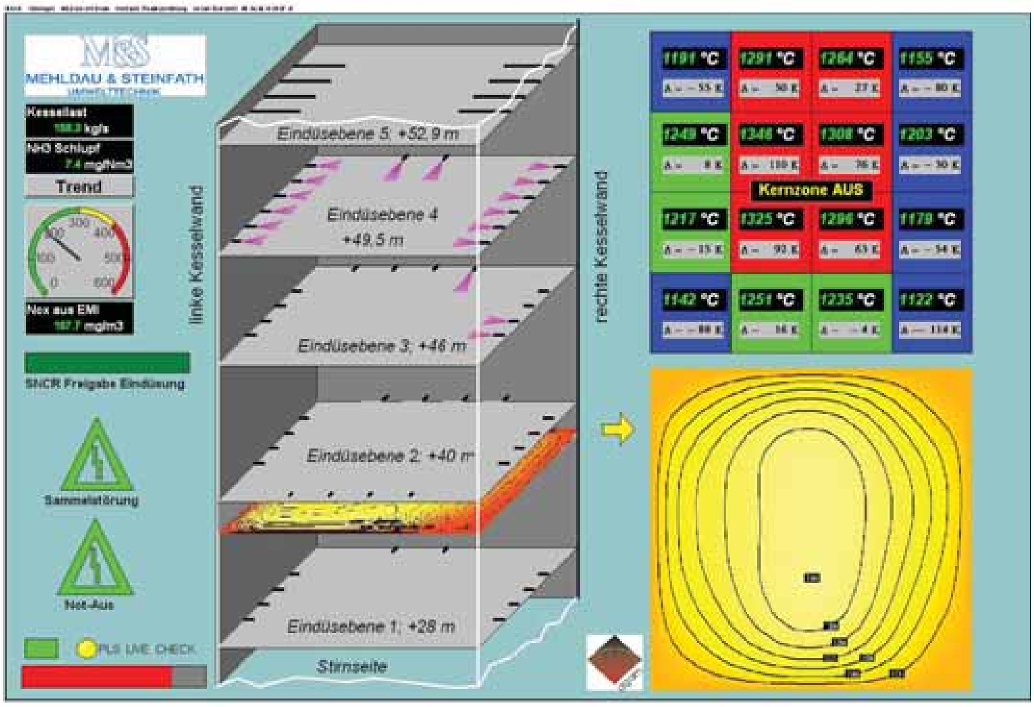
No:	Date	Boiler-Load	NO_X - Base Line mg/Nm³ *	NO_X with SNCR mg/Nm³ *	NO_X-reduction	
					mg/Nm³	%
1	08.10.2009	100%	197,8	125,3	72	36,7
2	16.09.2009	90%	233,6	137,0	97	41,4
3	06.10.2009	75%	232,3	97,8	134	57,9
4	07.10.2009	60%	150,0	75,0	75	50,0
5	18.09.2009	40%	456,1	244,3	212	46,4

Table 2: NOx Reduction with SNCR Demonstration Plant at different Boiler Loads

10. Operating results with a commercial SNCR in a 200 MWel coal fired plant.

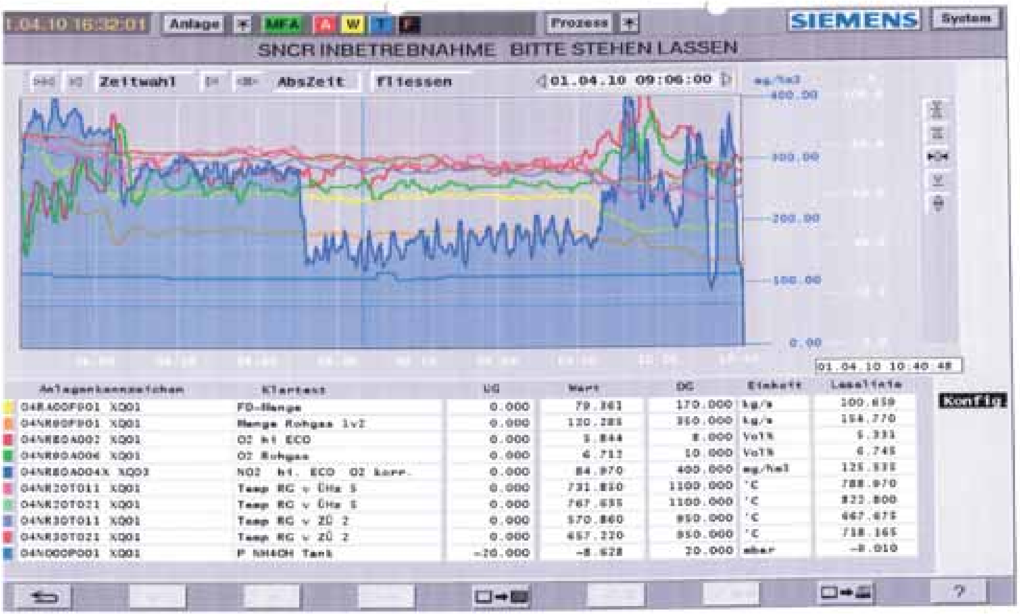
The SNCR plant was put into operation in March 2010. The guaranteed NOx and NH_3 clean gas values were instantly reached in most of the boiler loads between 20 % and 100 %. ranges. The subsequent optimisation phase was very time consuming, because in each of the five injecting levels the temperature profile had to be measured at various loads with suction pyrometers in order to calculate the difference to the temperatures measured with the acoustic temperature measuring system (agam). This was necessary in order to define which lance should be operated depending on the average temperatures in the zones and at which temperature the switching should be effected at the respective load. Beside this the settings of pressures and flow rates of the fluids ammonia water, demineralised water and compressed air had to be adapted according to the operating conditions.

The principle of the operation of the SNCR following the temperature profiles established with the acoustic temperature measuring system (agam) is illustrated on the display of the control system **(Figure 18)**. The level of NOx reduction and the quick reaction after injection of ammonia water can be seen on **Figure 19**.



1191 °C Δ = −55 K	1291 °C Δ = 50 K	1264 °C Δ = 27 K	1155 °C Δ = −80 K
1249 °C Δ = 8 K	1346 °C Δ = 110 K	1308 °C Δ = 76 K	1203 °C Δ = −30 K
1217 °C Δ = −15 K	1325 °C Δ = 92 K	1296 °C Δ = 63 K	1179 °C Δ = −54 K
1142 °C Δ = −88 K	1251 °C Δ = 16 K	1235 °C Δ = −4 K	1122 °C Δ = −114 K

Fig. 18: Display of Temperature Profile, Average Temperature in Zones, Injectors in operation



Anlagenkennzeichen	Klartext	UG	Wert	OG	Einheit	[illegible]
04RA00F001 XQ01	FD-Menge	0.000	79.361	170.000	kg/s	100.650
04NR80F001 XQ01	Menge Rohgas 1v2	0.000	120.285	310.000	kg/s	156.770
04NR80A002 XQ01	O2 hi ECO	0.000	5.844	8.000	Vol%	5.331
04NR80A006 XQ01	O2 Rohgas	0.000	6.712	10.000	Vol%	6.745
04NR80A004X XQ03	NO2 hi. ECO O2 korr.	0.000	84.870	400.000	mg/Nm3	125.535
04NR20T011 XQ01	Temp RG v ÜHz 5	0.000	731.810	1100.000	°C	788.970
04NR20T021 XQ01	Temp RG v ÜHz 5	0.000	767.655	1100.000	°C	822.800
04NR30T011 XQ01	Temp RG v ZÜ 2	0.000	570.860	850.000	°C	667.675
04NR30T021 XQ01	Temp RG v ZÜ 2	0.000	657.220	850.000	°C	718.165
04N000P001 XQ01	P NH4OH Tank	-20.000	-8.628	20.000	mbar	-8.010

Fig. 19: Results of NOx Reduction

11. Summary and outlook

Over a long-term continuous operation in various combustion plants the SNCR process has proven to be a reliable and economical process for NOx reduction to meet the required NOx limits. Also in the discussed power plants all expectations were fulfilled by the tests and mostly exceeded to a considerable extent. From the process point of view it is practically of no relevance whether urea solution or ammonia water is used as a reductant. If plants are engineered, installed and operated in an appropriate manner, both media are not expected to have an impact on the availability of the overall plant.

The results obtained in several incineration plants during operation prove that NOx clean gas values <100mg/Nm³ at a NH_3 slip <10 mg/Nm³ can be permanently achieved, and even values considerably below these figures are realistic. Reliable results are available, for instance, from a waste incineration plant in Germany, proving that NOx clean gas values of 70 mg/Nm³ at a NH_3 slip of <8 mg/Nm³ have been maintained over a longer period of time.

In Germany, Sweden and the Netherlands SNCR plants have been operated for several years, which have been designed for NOx limits of <100 mg/Nm³ and reliably comply with the guaranteed values in continuous operation. The newer plants of them, which are equipped with an acoustic temperature measurement (agam) and three injection levels to switch each individual lance, are characterised by a specifically low NH_3 slip apart from their low NOx clean gas values and high efficiency.

Although slightly higher NOx reduction levels are achievable with the SCR technology compared to the SNCR technology the cost-benefit ratio is seldom reasonable - in particular when considering the fact that meanwhile NOx values of 350 mg/Nm³ or lower are often obtained with combustion modifications alone.

During the decision making process it also should be considered that the protection level for the environment in the meaning of the BAT is not achieved considering the fact that the investment costs for a SCR plant alone, for instance, are so high that five to ten SNCR plants could be build for that amount – each of them would be able to ensure the compliance with the future NOx regulations and all these plants together would mean multiple relief for the environment and the costs for the owners compared to one SCR plant alone.

M & S has relevant experience both with urea and ammonia water and hence is able to offer and implement customised proposals for a cost-effective solution of the NOx problems, thus complying with, and in many cases even exceeding, the legal requirements for large combustion plants.

Test results from other combustion plants with an electric output of up to 225 MW are promising. In the accession countries Poland and the Czech Republic first decisions in favour of the SNCR technology for large power plants are expected to be taken in the course of 2010/11.

12. Literature

Von der Heide, B. et al.: NOx-Minderung an einem steinkohlebefeuerten Kessel in der ehemaligen CSFR nach dem NOxOUT-Verfahren. VGB-Konferenz „Kraftwerk und Umwelt 1993“, Essen. 28. April 1993

Chvalina J., Seitz A., von der Heide, B.: „Langjährige Erfahrungen mit nichtkatalytischer Entstickung in kohlegefeuerten Kesseln in der Tschechischen Republik“, VGB-Tagung, Düsseldorf, 17. April 1997

Grimard, F.X., von der Heide, B.: „Long-Term Experiences with Non-Catalytic NOx Reduction in Municipal Waste Incinerators“, POWER GEN, Madrid, 17.-19. Juni 1997

Kutlovsky, J., von der Heide, B.: „Experience in Controlling NOx from Utility Boilers with SNCR using Urea and Ammonia as Reagent“, POWER GEN, Frankfurt, 1999.

von der Heide, B.; Bärnthaler K.; Barok I.:“ Nichtkatalytische Entstickung von Rauchgasen aus zwei Kesseln mit Schmelzkammerfeuerung im Kraftwerk Vojany, Slowakische Republik“, VGB-Konferenz Kraftwerk und Umwelt 2000, 4.-5.4.2000 in Leipzig

Thomé E.: „Stickoxidminderungsmaßnahmen bei Abfallverbrennungsanlagen“ in: Thomé-Kosmiensky, K. J.: (Hrsg.): Optimierung der Abfallverbrennung 2. Neuruppin: TK Verlag Karl Thomé-Kosmiensky, 2005, S. 373 - 401

Deuster M.: „Akustische Gastemperaturmesstechnik“, VDI Wissensforum, Technische Temperaturmessung, Seminar 361101

Kaufmann, K. et. al.: „The Combustion of Different Fuels in al 180 MW th Circulating Fluidized Bed Steam Generator in Świecie (Poland), Power-Gen Europe, 28.-30. Juni 2005 in Milano

von der Heide, B.: „Ist das SNCR-Verfahren noch Stand der Technik“ in:
Thomé-Kosmiensky, Michael Beckmann (Hrsg.): Energie aus Abfall – Band 4. Neuruppin: TK Verlag Karl Thomé-Kosmiensky, 2008, S. 275 – 293

von der Heide, Bernd: “SNCR Process –Best Available Technology for NOx Reduction in Waste to Energy Plants”,
Power-Gen Europe, Milan, June 3 – 5, 2008

von der Heide, B. Langer, P.: Effizienz und Wartungsfreundlichkeit des SNCR-Verfahrens Thomé-Kosmiensky, Michael Beckmann (Hrsg.): Energie aus Abfall – Band 7. Neuruppin: TK Verlag Karl Thomé-Kosmiensky, 2010, S. 729 – 753

von der Heide, Bernd: “Advanced SNCR Technology for Coal Fired Boilers –200 MWel in Germany and 225 MWel in Poland”,
Power-Gen Europe, Amsterdam, July 3 – 5, 2010

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MEHLDAU & STEINFATH
UMWELTTECHNIK

Mehldau & Steinfath
Umwelttechnik GmbH
Alfredstraße 279
45133 Essen
Germany

Tel.: +49 (2 01) 4 37 83-0
Fax: +49 (2 01) 4 37 83-33
zentrale@ms-umwelt.de
www.ms-umwelt.de